Feather evolution and flight in dinosaurs

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Birds: 10,000 spp.

Descendants of a large and ancient radiation
The oldest fossil bird *Archaeopteryx*

140 Mya
Solnhofen, Bavaria

teeth
bony tail
long-fingered hands

+ flight feathers
Outline

-The research question

-First ½: The fossil record

-Second ½: Dinosaur flight

-Conclusion
The research question

Proavis
F Nopsca 1907

How did bird flight evolve?

‘Ground up’ or ‘trees down’?
Reconstructing the flight ability of fossil animals

FIG. 7. TETRAPTERYX STAGE IN THE ANCESTRY OF BIRDS
The drawing is based on characters present in Archaeopteryx, and in the young of living birds
Some necessary geological background

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<th>Era</th>
<th>Period</th>
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- Northeast China
- Jehol Biota (133-120 Mya)
- Early Cretaceous age (cf. IOW)
- 000s of specimens (inc. dinosaurs, birds)
- augment a global record of theropods
Evidence in support of the ‘theropod hypothesis’ is overwhelming

- **Osteology**
- **Oology**
- **Behaviour**
- **Integument**
Birds: just one lineage of “feathered” theropod dinosaurs

Ques: Which lineage is closest to *Archaeopteryx* (hence ‘birds’)

*Sinornithosaurus*: dromaeosaurid

*Anchiornis*-like: troodontid
The maniraptoran theropod dinosaur radiation

Bipedal dinosaurs with elongate, tridactyl hands with enlarged, semilunate carpals
First candidate lineage - troodontids

Robust metatarsal IV

Small and numerous teeth

Specialized second toe
Anchiornis is a Chinese troodontid with four wings.
Anchiornis is a Chinese troodontid with five wings.
Anchiornis is a Chinese troodontid with five wings.
First candidate lineage - troodontids

‘the sleeping dinosaur’

Mei
First candidate lineage - troodontids

*Xiaotinga* raised the possibility that *Archaeopteryx* could be a troodontid
Evolutionary relationships

Mei: troodontid

Samrukia

Archaeopteryx: troodontid

Nodal supports (from 10000 trees, cut 0)
Evolutionary relationships: our latest work

Eosinopteryx
Rigid tail with vertebrae strongly connected to one another

Second candidate lineage - dromaeosaurids

Powerful claw on second toe
Second candidate lineage - dromaeosaurids
Second candidate lineage – dromaeosaurids

*Microraptor gui*
Second candidate lineage – dromaeosaurids

*Microraptor gui*

- *Microraptor* had 4-5 wings
- Beebe (1914)
- Nature of flight and wing configuration has been much debated

-? Close to the origin of birds (*Archaeopteryx*)
In summary

**Dromaeosaurids:** mostly stocky-limbed maniraptorans, include very large *Utahraptor* (7 m long), long-snouted unenlagiines and microraptorines.

**Microraptorines:** small, feathered maniraptorans from Lower Cretaceous China and Upper Cretaceous North America. Some were ‘four-winged’.

**Troodontids:** Late Jurassic-Cretaceous maniraptorans, similar to dromaeosaurids in some details but with shorter arms and longer legs. Characterised by a high number of closely packed teeth. Some cursorial.
What we know about feather evolution in dinosaurs
Modelling *Microraptor*

- accurate geometries, joint morphologies and feathering (pigeons and ducks)
- previous reconstructions based on flat models, or speculation based (more or less) on fossils
- No consensus on likely wing configurations (thus degree of stability and glide performance) has been attained, reflected in a factor of six range of predicted lift-to-drag (L/D) ratios.

- L/D is one fundamental measure of flight performance determining minimum glide angle and thus maximum flight range under steady conditions.
Experimental results (i)

- Range of flight velocities and whole animal angles of attack
- 8 different configurations (all previously proposed that are anatomically viable)
- 3 different leg configurations, 3 main wing angles of incidence relative to the body and 3 different tail sizes
- 4 different flight velocities (covering the range consistent with those experienced by living gliding and flapping animals): 5 m/sec to 20 m/sec

(a)
Experimental results (i)

-L/D glide polars for the model *Microraptor* in different configurations (b) and pitching moment coefficient against aerodynamic force (c)

-Data show that configurations with a low angle between the main wings and tail had increased glide efficiency at high values of Cr, while altering the size of *Microraptor’s* tail made no significant difference to its aerodynamic characteristics.
Experimental results (ii)

- Envelope curve (best achievable L/D at any given aerodynamic force Cr)
- Configurations with sprawled legs had higher L/D ratios at low values of Cr (CL) but this changed as Cr increased
- Legs down configuration showing very slight superiority at high Cr values
-Unstable is better for sustained glide
-Better off adopting a high lift wing configuration, to generate high lift at low speed (minimise initial height loss from moderate heights, e.g. trees)

-High CL & high drag adaptive for Jehol Fm podocarp forest
Liaoning: fine-grained lacustine sediments
AMNH diorama,
photo Roderick Mickens

Wealden: floodplain-dominated
Wessex Fm scene, image M. Witton
Predictions

-Glide path simulation shows that *Microraptor* would have performed best in shallow glide with its legs held down.

-Best performing of all possible configurations is an anatomically impossible *Microraptor* without legs (= evolution of hindlimb feathering) (next best is with legs down).

-Achieving a high CL was most important for *Microraptor*’s flight (arguments about wing configuration and leg position less critical) (so wing area is key).

-Differences in gliding leg position only lead to very small differences in performance, a legs down configuration is most likely.
Legs down is anatomically most likely

Alexander’s KU model

Hesperonychus
Conclusion: the flight of *Microraptor*

-The most important factor for this theropod was attaining sufficient wing area (for which derived feathers are unnecessary); theoretically, all *Microraptor* needed to glide at high CL was an impervious surface.

-Comparing feathered and unfeathered models (flat plate experiments, SOM) demonstrates that the well-developed asymmetric feathers of *Microraptor* were not necessary to support its high CL (close to stall) flight style.

-Congruent with, and builds on, fossil evidence that shows theropod filamentous integument and symmetric wing feathers first evolved for behaviours other than lift generation.
Is this realistic? Didn’t these dinosaurs flap?

Confuciusornis

Archaeopteryx

Microraptor
Is this realistic? Didn’t these dinosaurs flap?
Is this realistic? Didn’t these dinosaurs flap?

Moment arm (Nm) plotted against rachis diameter (m)

The line describes the theoretical critical buckling moment as a function of thin-walled cylinder diameter
Open circles are hypothetical points for feathers of a diameter equal to that predicted for an extant bird with feathers of the same length

The feathers of *Confuciusornis* are 100 times, and those of *Archaeopteryx* 10 times, less stiff (less resistant to bending) than those of a comparably sized extant bird
Is this realistic? Didn’t these dinosaurs flap?

- Confuciusornisines
- Enantiornithines
- Ornithurines

100 mya

150 mya

>150 mya

from theropod dinosaurs

long primaries

to modern birds

100 mya

Archaeopteryx

Archaeopteryx

Confuciusornis
If not for flight, then why did feathers evolve?
If not for flight, then why did feathers evolve?:
additional fossil evidence
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‘the sleeping dinosaur’
If not for flight, then why did feathers evolve?: one possible mechanism